The Use of Injury Severity Scoring Systems to Predict Treatment Processes, Costs, and Outcomes of Spinal Trauma Patients in New Zealand

Undergraduate Research Thesis

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By

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Abstract

Using a multivariate linear regression approach, I examine the predictive value of retroactive injury severity scoring systems that are currently used as classification tools in trauma research. Understanding the potential impact of data gathered through specific scoring systems and how it can be used to better understand costs and outcomes, with a focus on New Zealand's spinal injury severity classification systems, is a new area of analysis. This paper introduces a novel understanding of the Abbreviated Injury Scale, and its ability to predict a variety of process and outcome variables related to spinal trauma care. Additionally, I make use of the unique cost structures in New Zealand to evaluate the predictive ability of the Injury Severity Score on cost and find a significant result.

Acknowledgements

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I. Introduction

Spinal injury is an increasingly critical health issue among many nations in the world[1-3]. The Oceanic island nation of New Zealand has a particularly high cause for concern due to high estimates of spinal injuries that have been occurring over the past few decades. The first widespread epidemiological analysis of spinal injuries in New Zealand, published in 1993, estimated the national incidence of spinal cord injuries in New Zealand to be approximately 49.1 per million/year[4] – which was considered the highest published national incidence rate of spinal injuries worldwide for many years; however, a specific cause for these high measures has not been conclusively determined[3]. A more recent study of both cord and non-cord injuries in New Zealand found similarly high estimates for the incidence of cord injuries in the Midland region (80 per million/year), as well as compelling rates of non-cord injuries (190 per million/year)[5]. Though the datasets and analytical approaches were not standardized, a preliminary comparison shows an incidence of 80 per million/year vs 49.1 per million/year, implying that the magnitude of the problem has likely increased in the past few decades[5].

Although global comparisons are often difficult to make due to a lack of data standardization[1-3], the basic comparisons that exist in the literature do imply that New Zealand shows the highest rates of spinal injury in comparison to other countries, yet it is by no means the only country struggling with these issues. Healthcare centers globally have witnessed increasing rates over the past few decades[3,4], and methods to classify and understand this trauma are becoming increasingly relevant as this rise occurs.

One such method is the Injury Severity Score (ISS): a scale used by healthcare practitioners to provide a numerical description of patients admitted to a healthcare facility for a trauma-related incident. The number is calculated by giving values to all injured regions of a person's body based on the severity of the specific bodily injury as outlined by the Abbreviated

Injury Scale (AIS) manual guidelines – with scores ranging from 1(minor) to 6(death). The ISS is equal to the sum of the squared AIS values for the top three most-injured body regions[12]. Coders determine these values retroactively, and these scores are not currently used in clinical decision-making. Even though the Injury Severity Score is used for all forms of trauma, it is relevant to patients who arrive at healthcare facilities with spinal injuries. It provides an effective method of describing emergent patients – especially patients with spinal injuries who often arrive with concurrent injuries – and provides a classification method that is used as a measure for comparison in clinical research studies. For instance, recent studies found that the percentage of minor injuries in New Zealand was about 83%, and that the most common AIS score was 2 (58%)[5]. Ultimately, this score seems to create a very influential yet simple way to better understand individual spinal trauma cases.

The ISS and AIS are currently only used to classify injuries in New Zealand, however, there is vast potential to incorporate these scoring systems into tools that can be used to predict expected costs, process measures, and outcomes in any spinal trauma patient that arrives in a hospital. At this point, there has not been a specific analysis of these scores in New Zealand, despite their unique circumstances as a high-risk nation for spinal injury. Additionally, the centralized medical system in New Zealand provides a unique cost structure that cannot be found in the U.S. and allows more accurate economic analysis of the true costs associated with varying levels of severity. This method of analysis would be far more difficult to conduct in the U.S. due to the complex nature of medical spending and health insurance in America, but the single-payer system in New Zealand provides the ability to calculate a straightforward measure of societal cost for hospital treatment. Neither the AIS nor ISS have previously been analyzed for their value in understanding delays to treatment. Lastly, the AIS has not been analyzed for its value in determining expected costs and outcomes to the extent that the ISS and variations of the ISS have been researched in the medical literature. Given the different aspects of severity these scales provide – with ISS being a more comprehensive measure of whole-body severity, and maximum AIS score being a measure of the single most-injured body region – there is potential to learn about how different presentations of trauma affect various care indicators. Developing a better understanding of the predictive value of these scales can make the case for whether it is worth scoring a patient upon arrival in New Zealand – using a model to determine their expected care pathway based on their score – as well as to learn which specific areas we can improve in the process of patient care.

II. Literature Review

Up to this point, a small amount of econometric analysis related to both spinal injuries and scaling systems has been conducted in both the medical and economic literature. As recently as 2012, there have been as few as 32 research articles in PubMed that utilize econometric analysis to understand issues in healthcare, and of these, only two are related to clinical outcomes[6]. The medical literature related to the incidence, prevalence, and causes of spinal injury is extensive, and researchers have gone into great detail to explain the Injury Severity Score and its level of accuracy for modeling severity through measures of mortality probabilities[7]. Early analysis of injury severity scoring methods found that they were predictive of both outcomes and costs in large databases of U.S. trauma, but some of this analysis is prior to the 21st century[8-10]. Sears et al (2014) measure cost and conduct an analysis using worker's compensation claims[11], however, this is very different from analyzing aggregate hospital costs. There are multiple articles that measure costs related to injury and morbidity to the patient and hospital[12-14], as well as economic cost trends over time[15]; however, a collective quantitative analysis of the cost, time delays, and patient outcome predictions using severity does not exist in the literature.

The economics research focused on clinical care is a growing part of the economics literature. Health economists often utilize standardized measuring tools such as QALYs (quality adjusted life years) or HYEs (healthy life years) to determine patient outcomes[16-18]. These scales could not be used in this study because they often incorporate aspects of injury severity to determine the weights for outcomes following a spinal injury[19]. Cost-benefit models are commonly used to analyze healthcare as well, including many studies related to healthcare policy initiatives[20-22]. Though these provide intriguing analysis, they are quite different from the focus of this paper and the topic of cost prediction using injury scale systems, as well as the effect of delays on costs.

III. Methods

A. Data

In order to conduct this analysis, secondary de-identified data was accessed from the Midland Trauma Registry – a database of trauma patients maintained by the Waikato District Health Board: a major regional hospital in the Midland region of New Zealand. The database contains pertinent information on any patient admitted to a hospital in the Midland region – Waikato, Taranaki, Tauranga, and Rotorua – as a result of any trauma, including spinal trauma. The data can range from basic demographic information to injury details, mechanism specifications, timing of treatment, hospital details, and severity scores. The inclusion criteria for the dataset is any patient admitted with a cord or non-cord spinal injury that did not die prior to hospital arrival. Between 1 January 2012 and 31 December 2015, 503 patients were included in the registry as a result of spinal trauma treated at the Waikato DHB, and these patients make up the dataset for this study. In-patient aggregated cost data pertaining to the 503 patients at the Waikato DHB is used for this analysis. Institutional Review Board approval is not necessary for this study since the de-identified data is coming from a secondary source, re-identification of the individuals is not possible with the given data, and no contact was made with the individuals being studied.

B. Empirical Approach

The data gathered will be analyzed using a multivariable linear regression approach with pooled cross-sections. To conduct the primary analysis, I assumed the following model:

$$Y_i = \beta_0 + \beta_1 \text{Severity}_i + \beta X_i + \varepsilon$$

The independent variables of interest are the injury severity scores of the patients, as well as the maximum Abbreviated Injury Scale scores. The dependent variables of interest include cost to the hospital (in NZD), length of stay (days), time in ICU (days), delay to CT scan (minutes), delay to operating room (minutes), delay to X-Ray (minutes), discharge destination, and mortality. The model was tested with multiple control variables – including patient gender, age, ethnicity, event rurality, type of injury, day of the week, and time of day. These variables could all potentially impact the outcome variables of interest due to the unintended associations between patient demographics and care indicators, as well as the changes in patient flow that occur in any given emergency department at various times.

Many of the qualitative variables were converted to binary dummy variables, including gender (1 = female vs 0=male), ethnicity (1=European vs 0=Non-European), event rurality (1=urban vs 0=rural), type of injury (1=cord vs 0=non-cord), discharge (1=home vs 0=not home), and mortality (1=died vs 0=survived). Since age was provided in 5-year age bands, the average of each band was computed to create a numerical variable. This introduces some error, but still provides some insight on how different age groups may affect the analysis. The day of week variable was converted from the date of arrival, and transformed into seven dummy variables, with ED arrival on Monday being excluded from the regression. The time of arrival was handled similarly, but with four 6-hour time blocks of morning (3AM-9AM), day (9AM-3PM), evening (3PM-9PM), and night (9PM-3AM) - the day dummy variable was excluded.

Length of stay and time in the ICU could be used as outcome measures because patients that spend a longer time in the hospital are likely dealing with a variety of additional complications that accompany long care timelines. Most hospitals prefer to discharge patients as soon as they are ready, so a long stay suggests concerns, yet there are flaws with this measure. Discharge destination and mortality are more direct outcome measures, since surviving treatment following a spinal injury and having the ability to return to one's home are important positive patient outcomes to consider. Furthermore, understanding the timing of treatment decisions will be relevant to understanding how we can predict delays to treatment based on severity, as well as what sort of effect, if any, delays have on costs to the hospital.

IV. Results

A. Descriptive Statistics

The sample of 503 patients used in the analysis presented with varying levels of severity, with ISS scores ranging from 1 to 43, and maximum AIS scores ranging from 1 to 5. Consistent with previous incidence studies, most injuries (77%) were minor in nature (ISS<13), as well as non-spinal cord injuries (71%). About 63% of the sample were male, 67% were of European descent, and 54% were employed after dropping individuals with missing information. Table 1 in the Appendix shows descriptive statistics of all continuous variables included in the regressions. As shown in Table 1, there were multiple instances where observations were missing from the data. When analyzing these variables, the missing individuals were dropped. Many of the continuous variables had right-skewed distributions and large standard errors, which is likely a result of the relatively small sample size.

B. Validity of Controls

To determine the controls that were necessary, I regressed the dependent variables of interest on each of the included controls. Employment status was not considered as a control variable due to the large number of individuals that did not provide employment information, as well as the lack of significance when comparing employment to all dependent variables. The significant results of these regressions can be found in the Appendix (Table 2). Age ($p=0.058$) and rurality ($p=0.054$) are correlated with cost. Age is also correlated with length of stay ($p=0.000$). Ethnicity ($p=0.002$) and ED arrival on a weekend ($p=0.011$) are related to the number of days in the ICU. Arriving in the ED between 3PM to 9PM is correlated with longer delays to the operating room ($p=0.000$) and X-Ray ($p=0.077$). Gender ($p=0.026$) and cord injuries ($p=0.030$) were associated with significant differences in delays to CT scan. Additionally, day of the week was correlated with delays to a CT scan, with Mondays showing consistent delays when compared to every other day of the week ($p=0.068$ to $p=0.455$). There were no significant relationships between any of the controls and final mortality. Lastly, patients arriving in the ED between 3PM and 9PM were estimated to be 7% less likely to be discharged home when compared to those arriving between 9AM and 3PM ($p=0.078$).

C. The Predictive Model

The main focus of this paper involved multivariate regression analysis that required running 16 OLS linear regression models, regressing each dependent variable on each independent variable, and including all control variables previously listed. Due to the increased variability in many of the dependent variables at the higher levels of severity, I used robust standard errors to account for any potential heteroskedasticity (Appendix: Figures 1, 2). The estimates for each of the regressions are shown below, with accompanying two-sided t-test results (Table 3). I tested the null hypothesis that the slope was equal to 0 and the alternative hypothesis that the slope was not equal to 0.

Table 3. T-tests of Slope Coefficients using Hypothesized Model

	ISS	95% CI	AIS	95% CI
Cost	2148.54*** (297.73)	(1563.52, 2733.56)	-3152.28** (1593.79)	(-6283.87, -20.49)
Length of Stay	0.773*** (0.105)	(0.566, 0.980)	-0.904* (0.499)	(-1.884, 0.075)
Time to CT	-2.350* (1.423)	(-5.155, 0.457)	-42.940** (20.082)	(-82.551, -3.328)
Time to OR	-7.178 (4.524)	(-16.117, 1.760)	129.231*** (49.166)	(32.085, 226.378)
Time to X-Ray	-1.054 (1.181)	(-3.384, 1.276)	-13.403 (12.875)	(-38.804, 11.998)
Discharge	-0.001 (0.003)	(-0.006, 0.004)	-0.163*** (0.033)	(-0.227, -0.099)
Time in ICU	-0.092 (0.328)	(-0.794, 0.611)	5.806** (2.362)	(0.741, 10.871)
Mortality	0.0003 (0.001)	(-0.001, 0.002)	0.002 (0.008)	(-0.014, 0.018)

SE in parenthesis
*p<0.10, **p<0.05, ***p<0.01

The results show some important findings. The regression of cost on ISS suggests that holding all else constant, a unit increase in the ISS leads to an additional cost of $2,148.54 – the R^2 for this regression is 0.36. As stated previously, this is useful because previous predictive analyses have relied on less direct measures of cost – such as worker's compensation claims – but due to New Zealand's lump-sum cost framework and centralized system, these monetary values are much more indicative of true cost to a hospital. The Injury Severity Score also seems to be highly predictive of length of stay, but unrelated to many of the other outcome and process indicators. The lack of predictability with delays to X-Ray is expected because the majority of spinal injuries will require a CT scan over an X-Ray due to the different details these two imaging techniques provide.

Given that the Abbreviated Injury Scale has not been previously analyzed using this method, the findings with respect to its predictive value on most of the included dependent variables are useful. All else held constant, a unit increase in AIS is significantly predictive of increased delays to the operating room (approximately 2 hours extra per unit), as well as a 16% decrease in the probability of being discharged home. The AIS models also suggest that holding all controls constant, increasing severity for the most severely injured region can also predict decreases in delays to a CT scan (by 42.94 minutes), decreased length of stay (by 0.9 days) increased time in the ICU (by 5.8 days), and decreased cost ($3152.28). The predictions of cost and length of stay between the two different scoring methods are unexpectedly opposite from each other in direction. This prompted a comparison of the two scales as shown below (Table 4).

Table 4. Comparing ISS to Maximum AIS Score (Y_i = ISS)

	Slope	t-statistic	p>|t|	95% Conf. Interval
Max AIS	-0.2887074 (0.4652)	-0.62	0.535	(-1.202681, 0.6252664)
Constant	8.72365 (0.9784)	8.92	0.000	(6.801379, 10.64592)
R^2 = 0.00, N = 503				

SE in parenthesis

The lack of a statistically significant relationship between these two scales is intriguing. It suggests that there is wide variation in how patients present to an emergency department when comparing their overall severity to their most severely injured region. It may also be the case that a patent’s most severely injured region is not necessarily a spinal injury, or that the maximum AIS score is a misleading measurement in this context. The patients with the highest overall severity may not necessarily have the highest single injury, but may instead have a multitude of slightly less severe injuries. If this potential explanation is true, this would mean that the ISS and AIS measure different aspects of severity, and it would make sense that the AIS and ISS are predictive of different indicators of care. A patient with a single, severely injured body region may have a different process of care and outcome when compared to a patient with multiple, more moderately injured regions. Determining which method of prediction (AIS vs. ISS) is better for determining expected cost and length of stay is an area for further analysis; however, I hypothesize that the Injury Severity Score is a more accurate predictor of both cost and length of stay because even when controlling for maximum AIS score in the regression, the ISS predicts increases in cost and increases in length of stay at a significant level, whereas AIS does not maintain a high level of significance when controlling for ISS. These results can be found in the Appendix (Tables 5, 6). Additionally, the ISS output provides a more intuitive result since one would expect cost and length of treatment to increase when the overall severity of a patient is higher. It is also possible that this finding is imprecise due to the relatively low sample size and lack of understanding AIS severity beyond the maximum score, but with the current data it is impossible to tell conclusively.

D. Analyzing Delays to Treatment

The final aspect of this project involved a more detailed analysis of delays to treatment, and how they could have an impact on cost. To approach this question, I utilized an instrumental variable approach. Given that delays to treatment can be a function of hospital flows due to increasing delays when a larger number of patients are present at a hospital, I measured the number of patients on various days of the week, as well as various times of the day. Based on this early analysis, I determined that the highest volumes of spinal trauma patients to the Waikato DHB were on weekends (Saturday and Sunday), as well as during the evening period (3PM – 9PM). Though there is no clear reason for why spinal traumas may be more likely on weekends, it could be argued that spinal traumas are more likely during the evening hours due to increased traffic leading to increased chances of road traffic collisions – a common mechanism of injury.

Based on the argument that the day of the week and the time of day that an injury occurs should be exogenous to an individual patient's cost, since severity is not associated with either of these, I considered using both a weekend dummy variable, as well as the evening dummy variable from the previous model, as potential instruments. Unfortunately, the weekend instrument did not pass the first stage of the IV approach, and was not correlated with delays to any type of treatment; however, I found a significant correlation between delays to the operating room and time of day (evening compared to day) at $p<0.001$. After running the 2SLS regression, controlling for age and event rurality, I did not find a significant causal effect of delays on cost (Table 7). Despite the lack of significance, there was a change in the coefficient from negative to positive between the OLS estimates and the IV estimates, suggesting that there could be increases in cost due to delays in receiving operational treatment when there are increased volumes of patients in an emergency department. It is possible that the lack of significance may be due to the limited sample size and resulting increased variability in the dataset, but there could be many other factors that are affecting the analysis as well.

V. Conclusion

Using a multivariate linear regression approach, I find that both the Injury Severity Score and Abbreviated Injury Scale can be used as predictive tools in spinal trauma care. While the ISS is predictive of cost and length of stay, the AIS is predictive of the probability of being discharged home, as well as delays to various forms of treatment. This establishes a baseline on the effectiveness of the AIS as an administrative tool in healthcare, while also validating the use of the ISS for similar purposes in the context of New Zealand's hospital framework. I have provided evidence to suggest that scoring a patient upon arrival could be used as a tool to determine the expected care pathways, as well as a method of learning where there are inefficiencies in the costs, processes, and outcomes of spinal trauma care. There are a few limitations of this study, such as the inherent discreteness of the scores – which creates particularly large bins in the AIS analysis – the difficulty in obtaining valuable patient outcome measures using the given dataset, and the relatively small sample size leading to large standard errors. One of the strengths of this study is the use of inpatient aggregated cost data, however these results are more difficult to interpret in the context of healthcare systems that do not use a centralized framework, such as the U.S. With that being said, even though there is significant global variety in the specific cost structures of healthcare, the results give us important implications regarding the societal cost of inputs to spinal trauma care that can be understood in the context of any healthcare system.

Ultimately, this study is impactful in the fields of both economics and medicine. It showcases the benefit of using econometric techniques to answering questions related to clinical care, highlighting a way of determining methods to achieve better efficiency and outcomes in healthcare systems. By developing a better understanding of the care process, we can use this information to make well-informed decisions about areas for improvement. Future studies may utilize larger sample sizes to further explore the effect of delays on hospital cost. Furthermore, given the widespread use of severity scoring in medicine, such as with cancer and other types of trauma, the implications of these results provide a groundwork for future studies in other fields of medicine using new scoring systems that would help increase understandings of care pathways throughout the medical field.

VI. Works Cited

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VII. Appendix

Table 1. Descriptive Statistics of Continuous Variables

	Mean	S.D.	Min	Max	N
ISS	8.149	7.096	1	43	503
Max AIS	1.990	0.681	1	5	503
Cost (NZD)	15371.84	26269.61	190	205128	499
Age	42.427	20.983	2	87	503
Days in ICU	6.900	7.810	1	35	30
Length of Stay	7.382	9.771	0	78	503
Delay to CT	136.284	180.201	4	1232	208
Delay to OR	625.875	467.492	4	1428	168
Delay to X-Ray	46.627	161.177	0	1433	201

Table 2. T-tests for Slope Coefficients of Dependent Variables on Controls

	Cost	Length Stay	ICU	OR	X-Ray	CT	Discharge	Mortality
Gender	-1094.94	-0.166	4.257	46.228	15.539	-61.558** (27.519)	0.014	0.016
Age	105.76* (55.69)	0.074*** (0.021)	0.067	1.299	0.318	0.903	0.001	0.000
Ethnicity	-3231.33	-0.084	-12.533*** (4.033)	27.100	5.580	-4.994	-0.048	0.011
Urban	-5360.50* (2771.59)	-0.750	3.528	83.547	-18.831	-44.003	0.012	-0.006
Cord Injury	1536.67	-0.142	-1.736	117.71	12.958	64.648** (29.569)	0.055	-0.005
ArriveTues	578.27	0.000	-0.456	-39.406	-0.596	-94.177* (52.230)	0.066	-0.025
ArriveWed	-656.10	0.547	4.249	-203.699	75.418* (43.301)	-60.486	0.027	0.004
ArriveThurs	5777.30	1.932	6.993	-59.802	4.106	-89.653* (48.824)	0.093	-0.023
ArriveFri	4422.24	1.775	3.019	45.825	-21.991	-46.577	0.073	-0.026
ArriveSat	3897.33	0.870	13.624** (4.834)	-29.682	8.238	-79.597* (47.371)	0.045	-0.011
ArriveSun	3702.00	0.786	8.611* (4.253)	39.241	24.369	-34.804	0.051	-0.015
ArriveMorning	-2717.80	-1.455	11.816	-112.907	4.072	-46.768	-0.088	0.032
ArriveEvening	642.66	-0.219	4.629	322.622*** (79.614)	47.102* (26.457)	9.879	-0.071* (0.040)	0.017
ArriveNight	-605.65	-0.487	3.000	204.228	26.723	19.866	-0.085	0.020
Adjusted R^2	0.00	0.01	0.26	0.10	-0.01	0.01	0.00	0.00

Table 5. Slope Coefficients with Regression of Both Scales and all Controls (Y_i = Cost)

	Slope	t-statistic	p>|t|	95% Conf. Interval
ISS	2142.38 (135.61)	15.80	0.000	(1875.90, 2408.85)
Max AIS	-2502.13 (1505.30)	-1.66	0.097	(-5459.96, 455.70)
Constant	4877.58 (5410.83)	0.90	0.368	(-5754.43, 15509.58)

Adjusted R^2 = 0.34, N = 497

SE in parenthesis

Table 6. Slope Coefficients with Regression of Both Scales and all Controls (Y_i = LOS)

	Slope	t-statistic	p>|t|	95% Conf. Interval
ISS	0.771 (0.053)	14.67	0.000	(0.668, 0.875)
Max AIS	-0.673 (0.583)	-1.15	0.852	(-1.819, 0.473)
Constant	0.391 (2.089)	0.19	0.852	(-3.715, 4.496)

Adjusted R^2 = 0.33, N = 498

SE in parenthesis

Table 7. OLS vs. IV Estimates of Delays to Operating Room on Cost

	(1)	(2)
Time to OR	-5.36 (6.11)	11.20 (18.79)
Age	27.73 (148.69)	19.02 (150.48)
Event Rurality	-8044.20 (6553.87)	-10247.81 (7024.73)
R^2	0.00	0.00
N	165	165

SE in parenthesis

Figure 1. Regression of Cost on Injury Severity Score

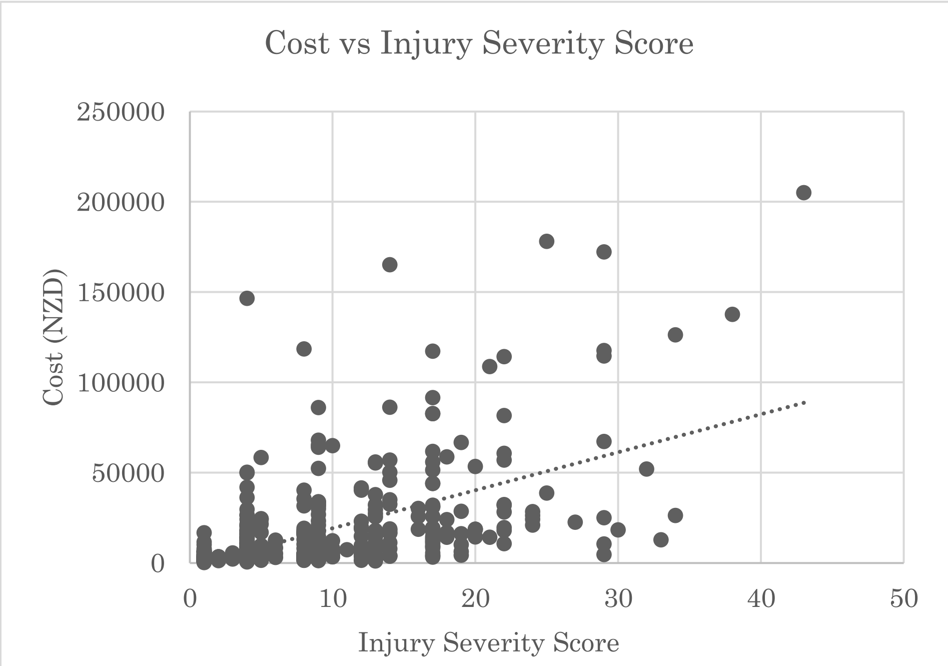
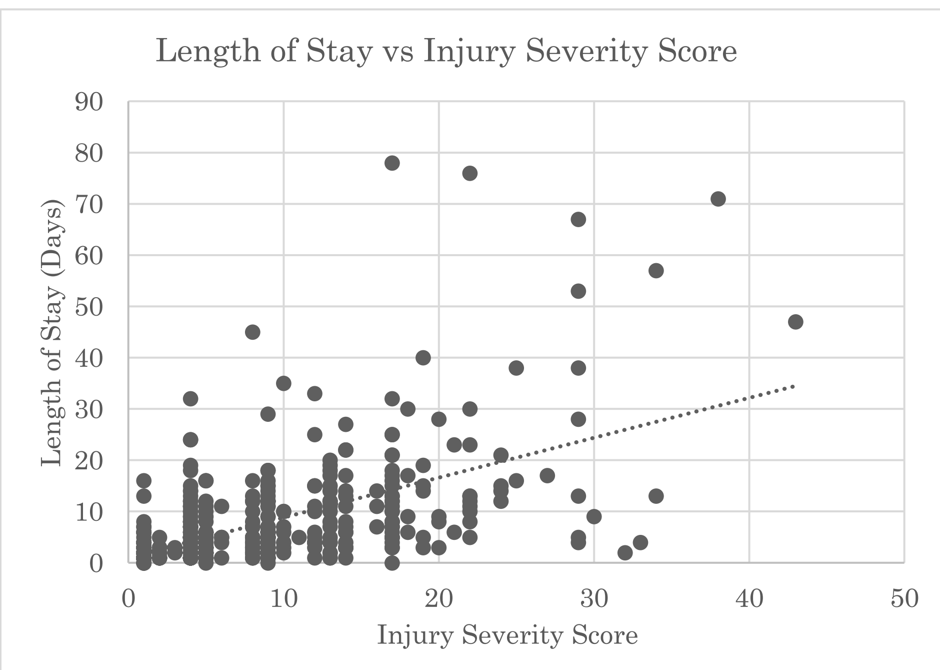


Figure 2. Regression of Length of Stay on Injury Severity Score



Dataset

Original list of variables provided by Midland Trauma Research Center:

1.) Injury Severity Score
2.) Major vs Minor
3.) Gender
4.) Age Band
5.) Ethnicity
6.) Employment Status
7.) Injury Year
8.) Injury Date
9.) Injury Time
10.) ED Arrival Date
11.) ED Arrival Time
12.) CT Received (Y/N)
13.) CT Date
14.) CT Time
15.) Same Day CT (Y/N)
16.) Time ED Arrival to CT
17.) Index CT Under 4 Hours (Y/N)
18.) Chest X-Ray Received (Y/N)
19.) Chest X-Ray Date
20.) Chest X-Ray Time
21.) Same Day Chest X-Ray (Y/N)
22.) Time ED Arrival to Chest X-Ray
23.) Went to Operating Room (Y/N)
24.) Operating Room Date
25.) Operating Room Time
26.) Same Day Operating Room (Y/N)
27.) Time ED Arrival to Operating Room
28.) Discharge Status
29.) Discharge Date
30.) Length of Stay (Days)
31.) Injury Intent
32.) GCS eye
33.) GCS verbal
34.) GCS motor
35.) GCS total
36.) Trauma Team Activation
37.) Ventilator Hours
38.) ICU Days
39.) Discharge Destination
40.) Event Rurality
41.) Cause
42.) Place of Injury
43.) Activity during Injury
44.) Final Status
45.) Cord vs Non-Cord
46.) Max AIS Score
47.) Cost (NZD)